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GENERAL DESCRIPTION OF DGPS BROADCAST SITE OPERATION

This nationwide DGPS service is based on the existing and proposed network of U.S. Coast Guard (USCG) and U.S. Army Corps of Engineers (COE) DGPS broadcast sites. This network, although designed to provide DGPS signal coverage to coastal areas, harbors, and inland waterways, by nature of the radiobeacon broadcast signal already provides coverage of over two thirds of the continental United States. A minimum number of additional DGPS broadcast sites are required to complete the nationwide coverage and provide the DGPS correction signal to all surface users. The broadcast sites that are added to the network will likely be added to the existing control stations that now monitor the USCG and COE DGPS broadcast sites. These redundant control stations provide real-time monitoring and control of the broadcast sites. Redundancy of the DGPS signal is obtained by designing the network of broadcast sites to provide overlapping coverage of the radiobeacon signal, so that a minimum of two DGPS correction signals can be received at most locations, nationwide.

2.1 GPS Constellation

The Department of Defense began development of the satellite-based GPS in 1973. The GPS constellation of 24 satellites in 6 orbital planes is now fully operational and provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours per day. The satellites complete an orbit every 11 hours and 56 minutes at an orbital height of 10,900 miles. The satellites are placed in their orbits so that a minimum of 5 will normally be observable by a user anywhere in the world. Positional accuracy available to authorized users of GPS, designated as Precise Positioning Service (PPS), is 21 meters (2drms). Authorized users employ the proper classified encryption keys and PPS-capable GPS receivers to extract the high accuracy encrypted signal. Due to encryption of the PPS signals, all non-authorized users have access to only the less accurate Standard Positioning Service (SPS). The DOD imposes Selective Availability (SA) on the SPS signal to deliberately reduce the navigation and timing accuracy of the system for non-authorized users. The military relies on SA and anti-spoofing (AS) procedures to deny full GPS accuracy to the enemy while maintaining use of the high accuracy signals for authorized users. SPS accuracy without SA is 54 meters (2drms). With the addition of SA and AS techniques, non-authorized user accuracy has been intentionally degraded to approximately 100 meters.

As soon as prototype GPS satellites were placed in orbit, long before full operational capability of the constellation, innovative civil users discovered economical applications for the available GPS signals. Industry, perceiving the growing demand for this service, developed and produced GPS receivers tailored to emerging civil market applications. As the civil use of GPS increased, the need for higher accuracy navigation and positioning signals was noted for many applications. This led to the development of DGPS, to augment the GPS signal and provide higher accuracy.

2.2 DGPS Description

DGPS is an enhancement of the GPS, through the use of differential corrections to the basic satellite measurements performed within the user's receiver. DGPS is based upon accurate knowledge of the geographic location of a reference station, which is used to compute corrections to GPS parameters and the resultant position solution. These differential corrections are then transmitted to DGPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 meters (2drms) to better than 10 meters (2drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution.[6]

The nationwide DGPS service described in these guidelines is modeled after the USCG's medium frequency radiobeacon system, DGPS broadcast sites. This service will incorporate the proven technology of the USCG system and build on the existing network of DGPS broadcast sites, with only a minimum number of additional DGPS broadcast sites required to complete the nationwide coverage and provide the DGPS correction signal to all surface users, as described in chapter 5 of these guidelines.

The nationwide DGPS service is comprised of a land-based system consisting of four main components, as shown in Figure 2.1.

1. A reference station, placed at a precisely surveyed position, which receives and processes GPS satellite position information from orbiting GPS satellites, calculates corrections from the known position, and broadcasts these corrections via a radiobeacon to participating DGPS users in the radiobeacon's coverage area.
2. A control station, which remotely monitors and controls the DGPS broadcast sites via data communications lines.
3. A communications link, which provides data communications between the broadcast sites and the control stations.
4. User equipment, consisting of a GPS receiver and a radiobeacon receiver or combination GPS/radiobeacon receiver, which automatically applies the corrections to received GPS position information, to achieve position accuracies of better than 10 meters.

2.3 Beacon System Broadcast Characteristics

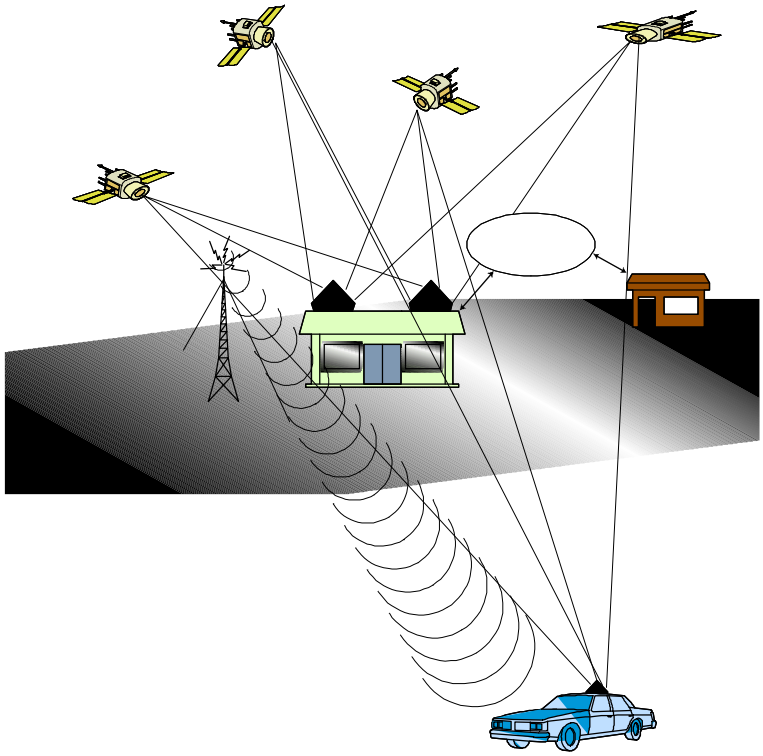

Figure 2.1. DGPS system.

The DGPS correction message, calculated by the broadcast site, is broadcast to the DGPS user by transmitting the information on a radiobeacon signal in the frequency range of 285 to 325 kHz. The eference station, placed at a precisely surveyed position, processes GPS satellite position information rom orbiting GPS satellites, calculates corrections from the known position of the reference station, nd modulates the correction messages onto the carrier of the radiobeacon. The corrections are ncoded as digital information using a form of phase modulation called Minimum Shift Keying MSK). MSK results in approximately a ±25 Hz shift in the carrier frequency of the radiobeacon (at 00 bits per second). The reference station generates two types of messages, Radio Technical ommission for Maritime use messages (RTCM) and Reference Station Integrity Monitor messages (RSIM).

RTCM type 9 messages contain corrections to the pseudoranges of the various satellites in view and are modulated onto the carrier of the radiobeacon for transmission to users' equipment. The RTCM format also allows DGPS site data to be flagged as unhealthy or un-monitored, providing notification

to the user of any potentially unreliable data. User receivers equipped with a DGPS beacon receiver can interpret the RTCM messages and automatically produce the corrected positional information whenever they are within range of a DGPS beacon. Accuracy of differentially corrected GPS signals is specified to be within 8 meters 95% of the time. Actual accuracy achieved by the user may depend upon the quality of their equipment and their distance from the DGPS site, but is typically much better than 8 meters.

RSIM messages contain information about the reference station's health and the reference station's confidence in the corrections generated. This confidence level is computed by the station's integrity monitor. RSIM messages are not broadcast, but are used for communication between the reference station, the integrity monitor, and the control station.

During normal operation the minimum field strength of the DGPS broadcast signal will be 75 microvolts per meter (uV/m) in the specified coverage area, at a transmission rate of 100 bits per second.[7] The location of broadcast sites, recommended in chapter 5, and the operating parameters of the beacon transmitters, are designed to provide this field strength over the specified coverage area. The recommended location of broadcast sites will provide signal coverage from at least two beacon transmitters, at most locations, nationwide. The reception of the beacon signal is dependent on the capabilities of the user's beacon receiver. Most beacon receivers will provide reception of the signal with field strengths of 10 uV/m or less, above the background noise level. The user receiver should always select the closest satisfactory beacon.

2.4 DGPS System Performance

The three major elements of DGPS system performance that are of concern to the user are accuracy, availability, and integrity. The position accuracy of the DGPS service will be within 8 meters (2drms) in all specified coverage areas. In most cases the accuracy will be better than 8 meters. A reasonable approximation for determining the achievable accuracy at a given point is to take the typical error at a short distance from the broadcast site (on the order of 0.5 meters), add an additional meter of error for each 150 kilometers of separation from the broadcast site, and add an additional 1.5 meters of error for the user equipment.[7] The actual position accuracy achieved is highly dependent on the user equipment, and the capability of this equipment is constantly being improved. From this it is easy to see that even at a distance of 300 kilometers from the broadcast site, a position accuracy of less than 5 meters can be obtained.

Availability of a given broadcast is defined as the percentage of time in a one month period during which a DGPS broadcast site transmits a healthy correction signal at the specified output level. The DGPS service was designed for, and is operated to maintain a broadcast availability level which exceeds 99.7%, assuming a complete and healthy satellite constellation is in place.[7]

The integrity of the broadcast DGPS correction signal is monitored continuously by the broadcast site, and at any time a problem is detected with the broadcast site equipment or the calculated correction, an alarm is transmitted to the user. The time from fault detection to transmission of an alarm to the user is a maximum of 4 seconds at the 100 bits per second transmission rate.

2.5 DGPS Signal Coverage

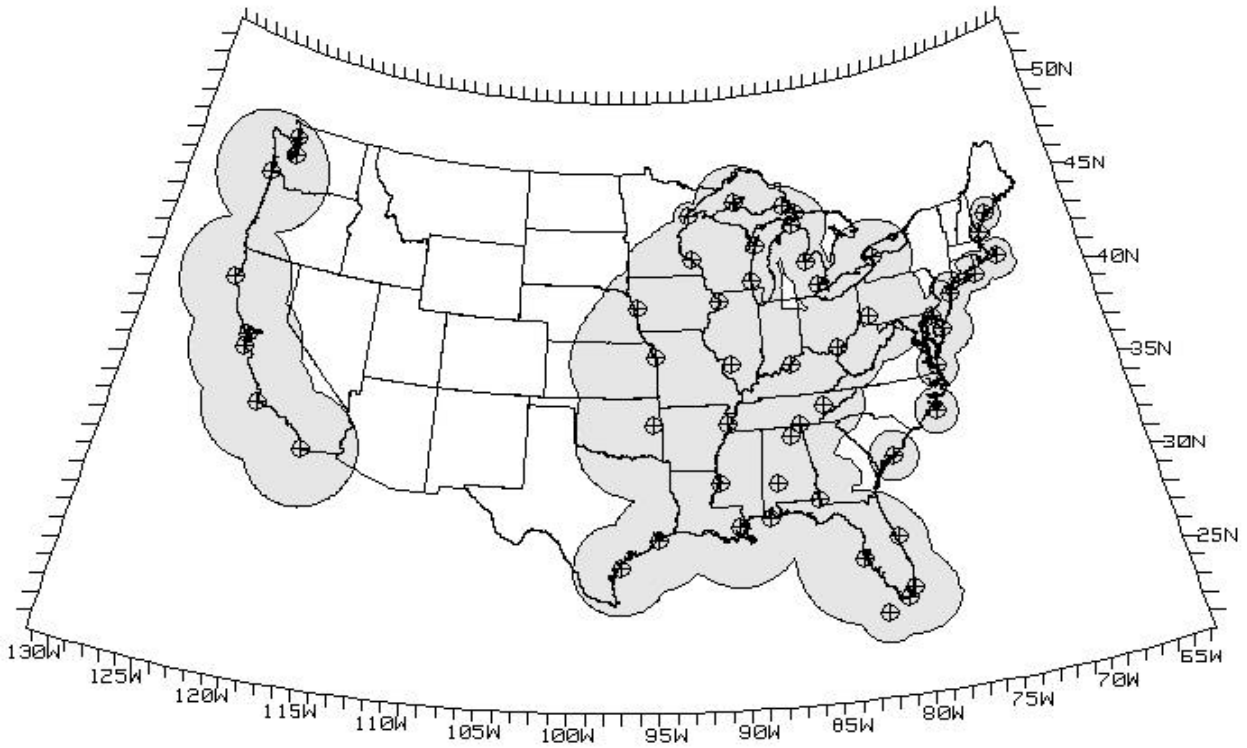

Figure 2.2. Existing DGPS radiobeacon signal coverage.

The network of DGPS broadcast sites now in operation or proposed by the USCG and COE provides DGPS signal coverage to coastal areas, harbors, and inland waterways. The network was originally designed to provide signal coverage for harbor and harbor approach areas, and other critical waterways for which the USCG provides aids to navigation. The service has been extended to provide coverage for the Great Lakes and the Mississippi River, resulting in a network of DGPS broadcast sites that provide radiobeacon signal coverage to over two thirds of the continental United States, as shown in figure 2.2.

The completion of a nationwide DGPS service that will provide signal coverage over the continental United States will require adding a minimum number of DGPS broadcast sites to this existing network. The signal coverage for the radiobeacon transmitters is aided by the use of the medium frequency 285 to 325 kHz band, which provides the advantages of a large coverage range with low power transmitters, and a minimum effect of terrain features on the propagation of radio waves. Redundancy of the DGPS signal is obtained by designing the network of broadcast sites to provide overlapping coverage of the radiobeacon signal so that at least two DGPS correction signals can be received at most locations, nationwide. The recommended location of additional broadcast sites and the operating parameters of these sites is covered in chapter 5 of these guidelines.

2.6 Control Stations

There are two existing DGPS control stations operated by the USCG, one in Alexandria VA., and one in Petaluma CA. The Alexandria VA. station handles all east and gulf coast sites and the Petaluma CA. station handles all west coast sites including Alaska and Hawaii. In the event of a failure at a control station, the other control station is capable of assuming operation of the total network. The broadcast sites that are added to the network will likely be added to these existing control stations, providing real-time monitoring and control of all broadcast sites.

The control stations are monitored 24 hours a day. Should any broadcast site develop problems, the control station will first take steps to correct the problem, and if appropriate, notify the local support of the malfunction. The control station software runs on the Coast Guard Tactical Advanced Computer system. This software allows the control station to check the status of each broadcast site, and provides control of the output modules at the control station, allowing remote resetting of the broadcast site equipment.

The control station is capable of logging raw DGPS data from broadcast sites for statistical analysis. This process allows the control station to verify the positions of the reference station and integrity monitor antennas to detect configuration errors, and to check for errors introduced by multipath signals or ionospheric conditions.